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research trends

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FORECASTING AVIATION'S GROWTH

by SEYMOUR J. DEITCHMAN

Prediction of aircraft types and of aviation activity have been made throughout the history of aviation. In general, later events have proved these forecasts to be inaccurate. Yet, this country invests well over $200 million each year in such aviation facilities as airports, communications, navigation and traffic control systems. Accurate forecasts are vitally necessary, therefore, to insure that these investments are made wisely, and to prevent air transportation from collapsing in utter chaos because of lack of proper facilities.

When Edward P. Curtis was appointed Special Assistant to President Eisenhower for Aviation Facilities Planning last year, he immediately sought a forecast of where aviation will go between 1956 and 1975. Curtis called upon the systems research analysts of three companies to evolve a forecasting method which would be as accurate as possible.

Airborne Instruments Laboratory, Aeronautical Research Foundation, and Cornell Aeronautical Laboratory pooled their special knowledge and skills in electronics, economics, aircraft design, and systems analysis to prepare this forecast. AIL, as prime contractor, coordinated the entire effort and measured present-day air traffic in selected areas of the country. ARF treated economic factors and all the facets of private and business aviation. CAL analyzed aircraft characteristics and operating economics, and covered that portion of the study dealing with military aviation.

FIG. 1 —The Vertol YH-16A, a possible prototype for the 50-passenger air bus.

Defining the Problem

The main problem facing the group was predicting the load on the nation's aviation facilities during the next 20 years in such a way that, should the prediction be in error, the facilities growing from the resulting plan would still be adequate. In essence, defining the facilities requirements was the first step in the systems research project. Measures of system loads were chosen and the factors influencing these measures were thoroughly investigated. Trends of each factor were then estimated separately, and these estimates were combined to forecast the total load on the system up to 1975.

The load on the system is measured by the number of aircraft movements (landings or take-offs) at a given place and in a given time, by the total number of airplanes that might appear in one control zone at any instant, and by the performance capabilities of all the aircraft in the group. For example, in 1956 there were about 85,000 aircraft in the continental United States. About 65% of these aircraft rarely flew above 10,000 feet; about 85% were incapable of flight over 300 mph. They made some 65 million take-offs and landings during the year; as many as 200 airplanes were airborne simultaneously within 50 miles of a major metropolis.

While it is important to obtain a reasonably accurate view of the trends in individual designs and the evolution of types within groups like the airline fleet, exact descriptions of future aircraft and their quantity are not in themselves of primary importance. However, large numbers of radically new types — such as a vertically rising, supersonic transport — may appear and have a major effect on the facilities system. Thus research effort had to be devoted to technological and economic analyses which would anticipate such trends.

The Economic Forecast

All aircraft fall logically into three classes: common carrier, which includes all airline aircraft carrying passengers or freight on a scheduled or non-scheduled basis; military (which cannot be discussed in this article because of security restrictions); and general aviation,

which includes all other aircraft. Each group has its own technological and economic structure.

A forecast of trends in the national economy was the first step in predicting trends in each of these three groups. This forecast, made by ARF, was based on the assumption that for the next 20 years we will continue to have an expanding, peacetime economy. From the expected economic growth of the nation, curves were derived showing the expected increase of disposable national income. The income was apportioned among necessities, such as housing and food, and taxes for military and other government expenditures. Portions of the national income available for travel were estimated for the years between 1956 and 1975.

At present, about 90% of all money available for travel is spent on the private automobile; the remaining 10% is divided among commuter travel within metropolitan areas, surface and air intercity carriers, and general aviation. ARF's economic forecast told how these divisions might be made in the future, thus indicating how much money would be available, year by year, for common carrier and other air travel.

Technological Developments in Transport Aircraft

At this point CAL's study of technical developments and the economics of individual aircraft operation came into the picture. Three possible technological developments can significantly influence the size and composition of the common carrier fleet: the advent of large turboprop or turbojet aircraft which travel at high subsonic speeds; the introduction of large (50-passenger or more) helicopters (Fig. 1) or airplanes which can operate from the same small mid-city areas served by the helicopters; and transport aircraft which can travel at supersonic speeds.

A survey of current designs and research effort, along with some rough design studies performed at CAL, showed that each of these developments will be technically possible before 1975. Large turbine-powered aircraft are, in fact, now under construction

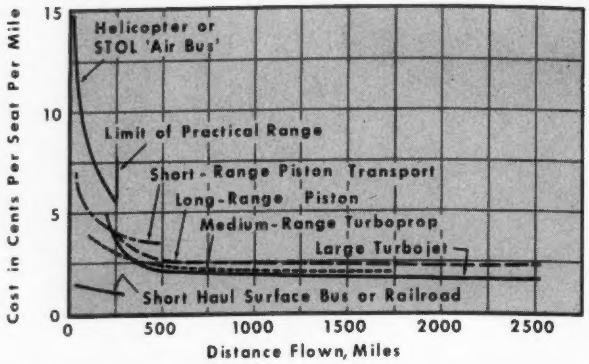

FIG. 2 — **Relative direct operating costs. Per-mile fares are determined by indirect as well as direct operating costs, and must be adjusted to compensate for the cost increase in short range flights.**

and will enter airline service in 1958. The 50-passenger helicopter or short-take-off-and-landing (STOL) airplane may appear any time after 1960. The supersonic transport is not now technically possible, but may well be after 1970.

What effect will these developments have on the form and size of the air traffic control system? First, the supersonic transport, whether or not it appears, should not have a large effect on the traffic control system. It must travel a great distance between stops if it is not to lose so much time (relative to its cruising flight time) in ground maneuvers, and in climbing and descending, that it will offer little net speed advantage over the fast subsonic airplane. Most passengers travel less than 500 miles, and only about 20% of the total fleet is used for trips of over 1000 miles. While supersonic transports may reduce this percentage, their effect on the size of the **entire** airline fleet will be negligible. Finally, even though supersonic transports might fly at 1200 mph at 50,000 feet, their flight characteristics near the airport, where they will mix in traffic with other aircraft, will not be very different from those of the subsonic jet transports.

The STOL airplane or helicopter, by offering fast, bus-type service in large cities like New York, or between city centers where conventional aircraft cannot enter might be expected to contribute an enormous amount of traffic activity. Such will not be the case. These aircraft require more power and fuel than ordinary aircraft to achieve their short-field characteristics; the resulting additional weight reduces their capacity to carry revenue-producing load. They must be operated, therefore, at a much higher fare per mile than conventional aircraft. As a result, the market for them would not be tremendous, according to the survey.

The Common Carrier Fleet

The real question is, then, what will happen to most of the common carrier airplane fleet, the "conventional" aircraft operated by the airlines? To answer this question, CAL chose a group of 37 aircraft designs, each having a different combination of speed, range, and passenger capacity. The Laboratory then calculated the cost of operating these airplanes, using the same method

THE COVER

CAL's large antenna and sensitive radio receiver at Wilson, N. Y., are probing the problems of long-distance transmission of UHF signals in a research program for the AF Cambridge Research Center. UHF signals are normally limited to line-of-sight transmission, but this antenna is picking up that very small part of the signal which is scattered in the troposphere.

The 915-megacycle signal originates at Lexington, Mass., nearly 400 miles away. It is monitored for 48-hour periods each week. Successful culmination of the research project will lead to refined theories on the atmospheric scattering of signals beyond the horizon.

FIG. 4 — Typical of tomorrow's aircraft: (a) Douglas DC-8 jet transport, carries 120-140 passengers at 500 mph; (b) Lockheed Electra turboprop transport, carries 66-91 passengers at 400 mph; (c) Fairchild F-27 turboprop transport for local service, carries 40 passengers; and (d) Beechcraft Bonanza, a four-place business aircraft.

employed by the airlines. This cost analysis (Fig. 2) showed what fares or freight rates might have to be charged. It also showed that, as airplanes become larger and faster, the fare necessary for profitable operation decreases.

Thus, it will be economically advantageous to operate large jet transports even on such relatively short flights as New York to Buffalo, San Francisco to Los Angeles, or Chicago to St. Louis, and to operate faster turboprop airplanes instead of the present piston-engine types over all flight distances. The use of large aircraft will be limited by the ability to find adequate airports and a sufficient number of passengers at smaller cities, so that some small transports will have to be retained.

CAL concluded that the proportion of large turboprop and turbojet aircraft in the airline fleet will increase as the years pass (Fig. 3). By 1970 airplanes may average nearly twice the seating capacity of today's

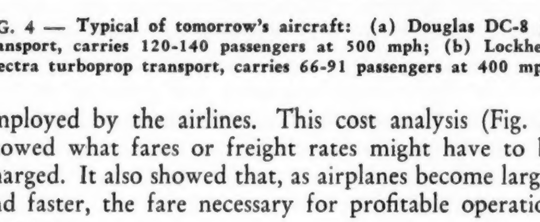

FIG. 3 — Evolution of the common carrier transport fleet. Some 250 jet airliners now on order will carry as many passengers as many miles as the entire domestic transport fleet did in 1956.

transports, and piston-engine airplanes may comprise only 20% of the airline fleet. These conclusions were tested by surveying airline plans for the future. Data showing the number and kinds of transports now owned and on order extended our knowledge of the fleet composition to about 1962, and indicated that our forecasts are reasonable.

Combining the data on operating costs with data on money available for common carrier travel led to an estimate of the number of people who would fly each year. This estimate, combined with the fleet composition described, disclosed that the airline fleet would remain about the same size as today: 1500 to 1800 airplanes. The airplane designs, typified by the forthcoming Lockheed Electra and Douglas DC-8 (Fig. 4), are generally known and the flight characteristics of the airplanes can be specified. These airplanes, by virtue of their greater size and speed, will be able to accommodate the increasing number of passengers traveling. They will also land and take off more frequently, so that the traffic control system might have to contend with one and a half to two times as many common carrier movements in 1975 as in 1956.

The General Aviation Fleet

The movements of common carrier aircraft amount to less than one-fourth of total civil aircraft movements; the remainder are contributed by general aviation aircraft, which include those used for business, pleasure and instruction, and for commercial applications like crop-dusting. Most of them are single-engine,

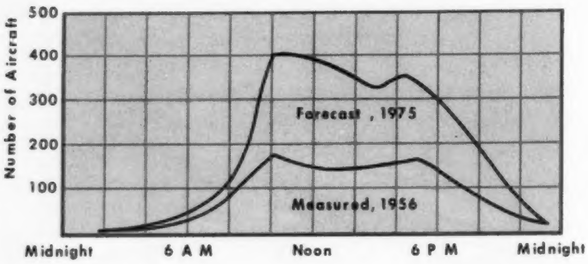

FIG. 5 — Variation of the total number of aircraft airborne within a 50-mile radius of New York City during a day of peak activity.

two- to five-passenger aircraft. Business airplanes total about one-third of the 60,000 general aviation aircraft and they do about half of the flying.

Unlike the common carrier fleet, the general aviation fleet is not amenable to a straightforward economic and technological analysis. Many intangible factors must be considered; for example, motivation. Many persons who like to fly cannot afford to own an airplane; eventually they may find that utility in business will justify its purchase. The financial predicament can then be overcome, because of tax benefits accrued on a legitimate business expense.

Although such intangibles make the prediction of general aviation growth very difficult, prediction of such growth is vitally important. The final forecast indicates that during the next 20 years the number of general aviation airplanes may increase to more than 100,000, of which about 60,000 will be business aircraft. The number of movements they contribute to the general traffic in some areas may triple today's figure.

Analyses of general aviation activity were made by ARF. Intangible factors — evaluated by extensive questionnaires and interviews with aircraft manufacturers, owners and potential owners, operators and salesmen — as well as the economic factors, were considered. The forecast represents the best estimate that can be made, yet we must accept the fact that it may be considerably in error, particularly in the later years of the forecast period. The best way to prevent such error from adversely affecting the planning for the traffic control system is to review the situation periodically, checking the forecast against actual events and revising the planning figures when necessary.

Two- to five-passenger, single-engine airplanes should continue to comprise about 85% of the general aviation fleet. Small twin-engine aircraft and a few transports similar to those operated by the airlines today will make up the rest of the fleet. Jet aircraft, because of their extremely high cost, will remain few in numbers. Small turboprops, whether or not they appear, will not differ enough from piston-engine aircraft to influence the demand on facilities.

A possible exception would be the advent of a cheap, all-weather STOL airplane, which could conceivably make the airways as crowded as our roads.

CAL and ARF investigated such a possibility through discussions with aircraft, engine, and automobile manufacturers. It was found that although the aircraft is technically feasible, the cost of developing it in a form suitable for mass production might be well over a billion dollars, and no one contemplates seriously such development in the foreseeable future.

Airborne Aircraft

A forecast of another measure of the load on the aviation facilities system — the total number of aircraft airborne in a traffic control zone at any instant — was also necessary. If the expected growth of each branch of aviation is known, then these growth factors can be applied to **today's** total number of instantaneously airborne aircraft to find how this number will increase in the future.

To obtain the basic data, AIL made radar counts of traffic during typical three-day periods around such areas as New York, Oklahoma City, and Albuquerque — which have representative high-, medium-, and low-traffic densities. Analysts measured the number of aircraft instantaneously airborne at half-hour periods throughout each day (Fig. 5), and then correlated results with information obtained from the CAA, military flight service centers, and airport towers. The correlation indicated the division among common carrier, general aviation, and military aircraft airborne at any instant. The separate growth factors were then applied to each category, and the total number of instantaneously airborne aircraft was forecast for future years. The peak value of this number, which does not exceed 250 in the busiest areas now, may grow to 400 over New York, and as high as 750 in the Los Angeles area, by 1975.

Use of the Forecast

The combined forecasts of the three measures of the load on the system, together with a mass of data on analyses and results, will permit planning of future aviation facilities, and indicate where additional research is needed. Emphasis in the forecasts has been on the needs of the system, rather than on details of aircraft design and exact numbers of aircraft.

Cornell Aeronautical Laboratory, Airborne Instruments Laboratory, and Aeronautical Research Foundation have tried to anticipate events that might have a radical effect on the system. They are reasonably certain that the entire forecast for the next five years, and parts of it for perhaps 10 or 15 years are accurate. Beyond that, it appears that the best insurance against incorrect forecasts — and ultimately against inadequate planning of air facilities — will be continuing observation and analysis of loads on the facilities system.

REPORTS

(NOTE: The following reports are based on the study made by CAL, ARF, and AIL for Mr. Curtis. They are available through the Government Printing Office, Washington, D.C.)

Final Report of National Requirements for Aviation Facilities: 1956-1975; June 1957.

Aviation Facilities Planning — A report by the President's Special Assistant; May 1957.

Modernizing the National System of Aviation Facilities; May 1957.

ANALOG COMPUTER *with Wings*

by JOHN L. BEILMAN

FIG. 1 — CAL's modified T-33 — a flying analog computer.

An important advance in aeronautical research is the development and use of an airplane in which new aerodynamic and control system configurations can be tested by merely changing a number of dial settings. Important parameters — such as wing span, tail area, and moments of inertia — can thus be varied as easily as on an analog computer. Significant advantages are obtained, however, over the earth-bound computer: the pilot is realistically included in the problem, experiencing all the forces involved; and his evaluation can be readily obtained without the necessity of building an airplane of the new design. Furthermore, the true response of the airplane is included, rather than its idealized mathematical representation.

The need for such a unique flight-testing tool lies in the design requirements for today's high-performance military aircraft. These radically different airplanes with swept-back, low-aspect-ratio wings, high wing loadings, and unconventional mass distributions have complicated the problems of achieving adequate stability and control characteristics.

In addition to the stability problems created by new configurations, operational needs are introducing more stringent requirements for the handling characteristics of military aircraft. The higher speeds of fighter airplanes have made for shorter runs on target. A higher degree of tracking accuracy is therefore required and the airplane's handling characteristics must be carefully matched to the pilot. One particular aspect of this question which merits special attention is the design of cockpit controls. The prevalent use of power control systems has opened the possibility of designing cockpit controls with a wide range of characteristics. A reexamination of the traditional use of wheel, stick, and pedal controls is in order. Can the controls be redesigned so as to make more accurate tracking of targets possible?

The general area of stability and control and handling characteristics of airplanes is thus developing in several ways. New knowledge and methods are being sought to cope with the various problems now arising.

Automatic Control Equipment

Several of the flight test programs which Cornell Aeronautical Laboratory has conducted for the Air Force have already demonstrated that the use of automatic control equipment in test airplanes provides a valuable tool for investigating stability and control problems. Such equipment has been used to vary many of the stability and control characteristics of test airplanes over wide ranges, effectively simulating other airplanes. This development has progressed to the point where a system has been designed and built to permit independent variation of all the important stability and control characteristics in one airplane.

When a new generation of airplanes is afflicted with stability and control problems, flight research can be undertaken by setting up the test airplane to simulate the undesirable characteristics; these characteristics can then be varied systematically and quickly so as to discover the promising approaches to the problem.

Simulating New Airplanes

A more general and far-reaching application is the simulation of new airplanes still in the design stages. For example, the new supersonic fighter airplanes tend to have low moments of inertia in roll compared to the moments of inertia about the pitch and yaw axes. The handling characteristics of such an airplane can be simulated well in advance of initial flight tests of the new airplane. If the results are not wholly favorable, variations in control system dynamics can be tried and various sorts of artificial stability devices can be simulated. From such tests come useful principles of design for the control systems of new types of airplanes.

It might also be that a new type of airplane designed to old criteria for handling characteristics would turn out to be unsatisfactory in some respects, even where it met the criteria. If this can be discovered early, current design can be oriented toward suitably revised criteria. In some cases, design calculations will predict that an airplane will have some unusual stability and control characteristic. Will this characteristic be satisfactory to a pilot and will it affect his ability to track a target or fly under instrument conditions? The answer is found by having pilots fly an airplane which has the characteristic.

A test airplane of the sort described is readily adaptable to research in the design of cockpit controls. This includes not only the physical design of the controls, but also the airplane's response to the controls. For

example, on a variable stability and control airplane, the effective gearing ratio between stick movement and elevator angle can be varied over wide ranges, or the control system can be set up to provide automatic turn coordination. One interesting possibility is to have a steady lateral stick deflection produce a steady bank angle instead of a constant rolling velocity.

Variable Stability Airplane

Under sponsorship of the Air Force's Air Research and Development Command, CAL is now conducting the flight checkout of a variable stability and control airplane on which work was initiated three years ago. A unique goal of the program was to make possible the simulation of five specific fighter airplanes of the Century series. The purpose was not so much to duplicate existing airplanes, as it was to set a criterion for the degree of flexibility desired for the system.

This variable stability airplane is an extensively modified T-33 jet trainer (Fig. 1). The elevator, aileron, and rudder controls in the front cockpit are disconnected from their respective control surfaces. They are connected instead to separate servomechanisms for each control (Fig. 2). To perform basic research on flight controls, this "artificial feel" system has been designed so that either a conventional stick or a wheel and column may be installed with equal facility.

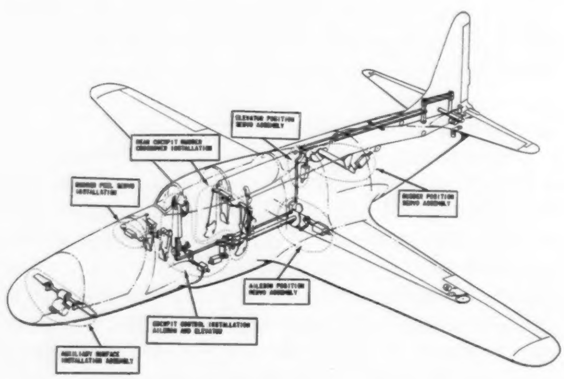

FIG. 2 — T-33A modified control system.

In addition, the elevator, aileron, and rudder control surfaces each have separate servos permanently connected to them. A fourth, or auxiliary, set of control surfaces has been added to the nose of the airplane for simulation and evaluation of the phugoid, or long period, oscillation. The original nose has been replaced with the larger nose of an F-94 to provide the volume required for the electronic components of the automatic control system (Fig. 3). Although most of the electronic components are installed in the nose, some are located in the cockpits, wheel-walls, wings, plenum chamber, and tail surfaces. Finally, a number of circuits, controls, and switches related to normal airplane functions have been modified or relocated to make the airplane more fully a "solo" airplane from the rear seat.

The rear pilot, or "safety" pilot, takes off and lands the airplane as a near-normal T-33. At test altitude

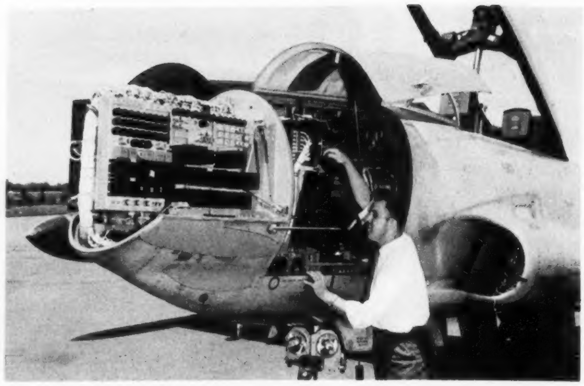

FIG. 3 — Electronic equipment of the automatic control system occupies the entire nose section of the T-33.

the safety pilot and the "evaluation" pilot perform the sequence of operations necessary to engage the automatic control system. When this procedure is completed the evaluation pilot has command of the airplane through the artificial feel controls. These are capable of providing the evaluation pilot with a wide range of static and dynamic control characteristics. For example, the elevator stick force gradient can be varied from one to several hundred pounds per inch of deflection.

Control Console

The safety pilot sets up the desired "airplane" before the automatic control system is engaged. This may be done conveniently before take-off, but it can also be done as part of the engage procedure when the test team wants to simulate several airplanes during a single flight. The safety pilot is able to set up or change the configuration of the automatic control system by means of a console in the rear cockpit (Fig. 4).

This console contains 40 miniature gain controls specially designed for this application. The setting of each control is presented as two digits so that the pilot may select any setting between 00 and 99. The controls are continuously adjustable between these limits, with a setting of 50 indicating zero gain for any particular signal. Numbers greater or less than 50 indicate positive or negative gains, respectively. Positive and negative refer to the sense of the control surface motion with respect to the signal producing the motion.

Eleven of the 40 gain controls are related to the evaluation pilot's artificial feel system. The other 29 affect the signals which are produced by the rigid body motions of the airplane (e.g., the linear and angular velocities and accelerations) and which are used to alter the airplane's response and stability characteristics. These signals are generated and modified in a variety of instruments carried in the airplane, including accelerometers, rate gyros, and attitude gyro, and a pressure-monitoring servo system. There are also three instrument-type servo systems which generate non-linear functions.

Each control surface can be moved, then, in response to the vector sum of a variety of signals, in-

cluding the signals representing the evaluation pilot's commands.

For example, the aileron and rudder can each be made to respond to the pilot's aileron and rudder commands, rolling and yawing velocity and acceleration,

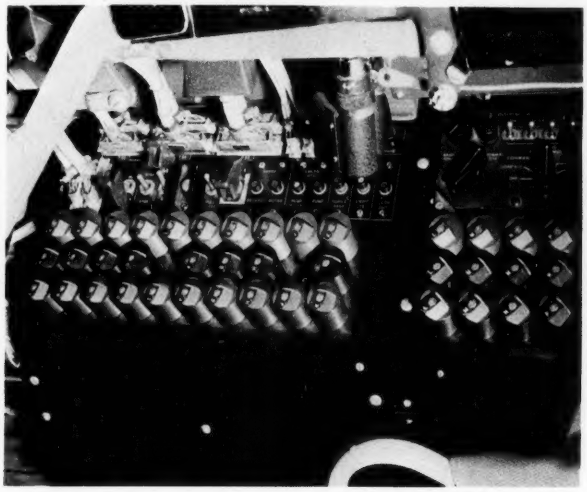

FIG. 4 — Automatic control console in rear cockpit.

and angle of sideslip and its rate of change. In addition, the aileron can respond to bank angle, and the rudder can respond to the product of angle of attack and rolling velocity, as well as to the product of angle of attack and the pilot's aileron command.

An airborne recording system provides for monitoring the system performance and for calibrating the system in flight. Twenty-four signals can be recorded. A novel feature of the recording system is a "sampling switch" which provides for the recording on one galvanometer of the position of every gain control and switch in the system which the pilot may use.

Electrically, the automatic control system is equivalent to a medium-size analog computer. It requires slightly more than 2 KVA of primary power and contains approximately 250 sub-miniature and miniature vacuum tubes in negative feedback amplifiers of a plug-in type. Signal circuits alone — exclusive of grounds, power, and control wiring — require over three miles of wire.

Numerous fail-safe features have been incorporated in the design. In addition there are circuits which will automatically disengage the system if any of the control-surface servo error signals exceeds a pre-determined value or if either the normal or lateral acceleration of the airplane reaches preset limits. Finally, relief valves are connected across the servo pistons so as to limit the maximum tail loads which the automatically controlled surfaces can produce.

As a research tool, the T-33 variable stability and control airplane promises to have a substantial life. A brief survey of Air Force needs indicates that several years may be required to complete the flight programs already proposed for study. An earlier CAL variable stability airplane, an F-94, familiarized the test pilot of the B-58 Hustler with that airplane's longitudinal handling qualities — before its first flight. The T-33 may well be expected to produce similar dramatic examples of the variable stability technique.

REPORTS

"Installation of an Automatic Control System in a T-33 Airplane for Variable Stability Flight Research;"

Part 1 — Preliminary Investigation and Design Studies; WADC TR 55-156, Part 1; CAL Report TB-936-F-1, April 1955.

Part 2 — Detail Design, Fabrication, and Installation; WADC TR 55-156, Part 2; CAL Report TB-936-F-2, September 1956.

"Flight Evaluations of Various Longitudinal Handling Qualities in a Variable Stability Jet Fighter;" Harper R. P., WADC TR 55-299, CAL Report TB-757-F-12, July 1955.

This research was supported in whole or in part by the United States Air Force under Contract Nr. AF33(616)-2578, monitored by Aeronautical Research Laboratory, WCRRN, Wright Air Development Center.

ABOUT THE AUTHORS

SEYMOUR J. DEITCHMAN, principal aeronautical engineer in the Systems Research Department, has been engaged extensively in transportation research recently. The tri-company study outlined in his article, "Forecasting Aviation's Growth," and a program to outline requirements for a collision-warning device have been his main responsibilities. His current professional interests embrace the whole field of transportation research, both ground and air.

Mr. Deitchman joined CAL in 1947, supervising and analyzing wind tunnel tests, and working on the design of a supersonic tunnel. After two years with Bell Aircraft in aerodynamic analysis and design, he returned to CAL in 1951 as project engineer on bomb separation studies, and more recently on the air transportation programs.

He has a BME from the College of the City of New York and an MSE from the University of Buffalo. From 1943 to 1947 he was employed by the National Advisory Committee for Aeronautics in aircraft stability and highspeed aerodynamic research.

JOHN L. BEILMAN, research electronics engineer in the Flight Research Department, has been working on variable stability systems at CAL since 1950 and is now engaged in the fourth and most extensive program — the T-33 project described in "Analog Computer With Wings." Mr. Beilman led the electrical design of this system, drawing upon knowledge acquired on Naval and Air Force projects on the F4U-5 and a non-linear yaw damping system for the F86-E. Earlier, he was an instrumentation engineer in a B-26 automatic tracking control program and on CAL's flight line computer programs.

Mr. Beilman served with the U.S. Navy in World War II as an airborne radar specialist attached to the Atlantic Fleet. After discharge in 1946 he returned to the Bell Aircraft Corp. where he had been employed prior to the war as a foreman in the Bomber Division. He joined CAL in October, 1946.

Attending the University of Buffalo evenings from 1946-1956, Mr. Beilman completed all course requirements leading to a B.A. degree with a major in Physics.

RECENT C. A. L. PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"MODEL INSTRUMENTATION TECHNIQUES FOR HEAT TRANSFER AND FORCE MEASUREMENTS IN A HYPERSONIC SHOCK TUNNEL," Vidal, Robert J.; CAL Report AD-917-A-1 (WADC TN 56-315); Feb. 1956; 76 pages.

Performance of a thin metal resistance thermometer mounted on an insulating body is analyzed and methods given for constructing such an instrument. An accelerometer balance system is described and its performance is analyzed.

"EFFECT OF THERMAL STRESSES ON THE AEROELASTIC STABILITY OF SUPERSONIC WINGS," Biot, M. A.; CAL Report SA-987-S-2; April 1956; 12 pages.

A simplified treatment, leading to an evaluation of the influence of thermal stresses on the wing stability, including the chordwise bending, the anticlastic effects, and the non-linear aspects due to finite deformation.

"NEW METHODS IN HEAT FLOW ANALYSIS WITH APPLICATION TO FLIGHT STRUCTURES," Biot, M. A.; CAL Report SA-987-S-3; May 1956; 60 pages.

New methods are presented for the analysis of transient heat flow in complex structures leading to drastic simplifications in the calculation and the possibility of including nonlinear and surface effects.

"INVESTIGATION OF HELICOPTER ROTOR FLUTTER AND LOAD AMPLIFICATION PROBLEMS," Daughaday, H., DuWaldt, F. and Gates, C.; CAL Report SB-862-S-4; Aug. 1956; 162 pages.

This report presents the results of an experimental and analytical investigation of two related aeroelastic problems of helicopter rotors, namely the dynamic amplification of blade loads and rotor blade flutter.

"FLIGHT EVALUATIONS OF THE EFFECT OF VARIABLE PHUGOID DAMPING IN A JTB-26B AIRPLANE," Newell, F. and Rhoads, Donald W.; CAL Report TB-969-F-1 (WADC TR 56-223); Oct. 1956; 46 pages.

This report establishes that phugoid damping is not a negligible parameter of good aircraft stability and control design, specifically when instrument flight is considered.

"DESIGN MANUAL FOR SPHERICAL AIR SUPPORTED RADOMES — (REVISED)," Bird, Walter W. and Kamrass, Murray; CAL Report UB-909-D-2 (WADC TR 56-101); March 1956; 145 pages.

Methods of analysis have been revised and a section covering the loading of the tower has been added. The latest information on new materials and equipment is summarized and the latest approved maintenance procedures are outlined.

"A TWO-DIMENSIONAL APPROXIMATION TO THE UNSTEADY AERODYNAMICS OF ROTARY WINGS," Loewy, Robert G.; CAL Report 75; Oct. 1955; 50 pages.

A two-dimensionalized model is postulated for the representation of the aerodynamics of an oscillating rotary wing airfoil operating at low inflow; forward speed effects are neglected.

"THE TIME VECTOR METHOD FOR ANALYZING THE LONGITUDINAL SHORT PERIOD OSCILLATION USING FLIGHT TEST DATA," Breuhaus, Waldemar O.; CAL Report FRM-260; Oct. 1956; 11 pages.

The time vector method, as developed for the lateral mode, has been extended for use in extracting the longitudinal stability derivatives from flight test data of free oscillatory motions of an aircraft.

"THE RAMPROP, A SUPERSONIC JET-DRIVEN PROPELLER," Gail, Albert; reprinted from "Zeitschrift fur Flugwissenschaften," 1956; 13 pages.

The structural and aerodynamic problems of ramprops are analyzed and a suitable design is proposed.

"SPECTRAL REFLECTANCE OF SOLIDS FOR ALUMINUM K RADIATION," Hendrick, Roy W.; reprinted from the Journal of the Optical Society of America; Feb. 1957; 7 pages.

The fraction of aluminum K radiation reflected from flat glass, magnesium, aluminum, copper, silver, and gold surfaces was measured as a function of the angle of grazing incidence.

"DISPLACEMENT THICKNESS OF THE UNSTEADY BOUNDARY LAYER," Moore, Franklin K. and Ostrach, Simon; reprinted from the Journal of the Aeronautical Sciences; Jan. 1957; 2 pages.

A note extending a previous result for the displacement effect of a 3-dimensional boundary layer to apply to the unsteady boundary layer, and to apply the result to certain flows for which unsteady boundary-layer solutions are available.

"SOME EXAMPLES OF LAMINAR BOUNDARY-LAYER FLOW ON ROTATING BLADES," Rott, Nicholas and Smith, William E.; reprinted from the Journal of the Aeronautical Sciences; Nov. 1956; 7 pages.

Further solutions to the problem studied by L. E. Fogarty — laminar flow over a cylindrical blade rotating steadily in an incompressible fluid.

"SOME PROBLEMS ASSOCIATED WITH INSTRUMENTING SHOCK TUBES FOR HYPERSONIC RESEARCH," Smith, William E. and Vidal, Robert J.; paper presented at the American Rocket Society Meeting; Sept. 1956; 16 pages.

Current practices and anticipated instrumentation developments, especially in the categories of pressure measurement and schlieren optics, are reviewed.

"NEW EXPRESSIONS FOR THE OUTPUT OF AN FM RECEIVER, WITH APPLICATION TO PROBLEMS OF INTERFERENCE," Kaufman, Sol and Biot, M. A.; CAL Report BE-745-T-134; Aug. 1956; 19 pages.

The expressions are obtained directly from the spectral representation of arbitrary superspeed input signals, and expressed as the quotient of two Fourier series. This quotient may be easily expanded in a Fourier series and the coefficients of the series evaluated by a method of residues.